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DIAGNOSTIC TECHNIQUES

Right Atrial Flow Topography in Healthy Subjects Studied With Real-Time Two-Dimensional Doppler Flow Imaging Technique

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The pattern of normal blood flow in the right atrial cavity was studied using the newly developed real-time two-dimensional Doppler flow imaging technique as a standard reference for the Doppler diagnosis of heart diseases with intracardiac shunts at the atrial level. The study was performed primarily with use of the apical four chamber and the parasternal right ventricular inflow tract views in 21 healthy subjects.

The following patterns were observed: blood from the inferior vena cava flowed up along the posterior wall of the right atrium and joined with blood from the superior vena cava in the posterocranial part of the right atrial cavity; the flow then coursed along the roof of the right atrium toward the tricuspid valve in the atrial relaxation phase. This flow was always noted along the interatrial septum in the four chamber view. During and after mid-systole of the right ventricle, additional blood flow away from the tricuspid valve appeared, moving from the valve to the central part of the right atrial cavity, that is, at the lower right of the preceding inflow; this flow was interpreted as arising from eddy currents caused by the preceding inflow. In early diastole of the right ventricle, the flow signal area along the interatrial septum and the roof of the right atrium extended into the right ventricular cavity through the tricuspid valve. In the atrial contraction phase only the blood near the tricuspid valve in the right atrial cavity appeared to flow into the right ventricular cavity. Inflow from the coronary sinus was almost undetectable.

In conclusion, the pathway of blood flowing into the right atrial cavity lies mainly along the posterior wall and then along the roof of the right atrium near the interatrial septum. The remaining portion of the right atrial cavity appears to contain pooled blood.

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The newly developed real-time two-dimensional Doppler flow imaging technique (1–4) provides new information on intracardiac flow topography. Various kinds of intracardiac flow are visualized in the color-coded mode and are characterized by anatomy.

Flow topography of the right atrial cavity is considered complicated, because the right atrial cavity receives inflow from three sources, that is, the superior and inferior venae cavae and the coronary sinus. In various cardiac diseases there is an intracardiac shunt from or into the right atrial cavity; such a shunt further complicates right atrial flow topography. The newly developed Doppler flow imaging technique is expected to be advantageous in analyzing and diagnosing such complicated conditions, and for this purpose, the normal flow topography in the right atrial cavity is an indispensable reference. In this study, we examined normal flow topography in the right atrial cavity using the real-time two-dimensional Doppler flow imaging technique.

Methods

Study group. The subjects were 21 healthy volunteers, aged 5 to 36 years (average 27), with no abnormal findings in their history, physical examination, electrocardiogram or two-dimensional echocardiogram.

Equipment. The equipment used was a real-time, two-dimensional Doppler flow imaging system, an ALOKA XA-54 prototype. Details of this system have been previously reported (4). In the flow image recorded by this equipment,

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flow moving toward the transducer is expressed in red and that away from the transducer in blue. The magnitude of flow velocity is measurable up to a Doppler frequency of 2 kHz. The measurable range is divided into eight grades at steps of 250 Hz. These grades are represented by increasing the brightness of the color, beginning from the lowest grade, which is not colored on the screen. Thus, flow with a velocity lower than 7.5 cm/s moving in the direction of the ultrasound beam is not displayed on the screen. To visualize the velocity spectrum variance, green is added to each color in proportion to the extent of turbulence. Accordingly, as the variance increases, the color hue shifts from red to yellow and from blue to light blue for blood flow toward and away from the transducer, respectively. The Doppler frequency spectrogram, based on the fast Fourier transform analysis, is also shown at a certain point in the two-dimensional flow image.

Recordings. The Doppler examination was carried out with subjects in the left lateral decubitus position. Blood flow patterns in the right atrium were examined in the apical four chamber view from the fourth intercostal space to the left of the sternum, and in the parasternal right ventricular inflow tract view. To image the ostium of the coronary sinus, it was advantageous to tilt the scanning plane for the apical four chamber view to bring down its left posterior part. With this maneuver, the left atrium disappeared from the visual field; this view, tentatively designated the parasternal three chamber view (5), was also examined. Flow velocity in the right atrium was simultaneously observed by conventional flow velocity analysis.

Results

Right atrial flow pattern observed from the apical four chamber view. In early right ventricular systole, flow signals were difficult to record in the right atrium in the apical four chamber view. It was assumed that there was no rapid flow in the right atrium during early systole. In 19 of the 21 subjects, a rapid flow toward the tricuspid valve was recorded along the interatrial septum in the right atrium during mid to late systole (Fig. 1,2). In late systole, a slow flow away from the tricuspid valve orifice was noted in the area between the tricuspid valve and the center of the atrium.

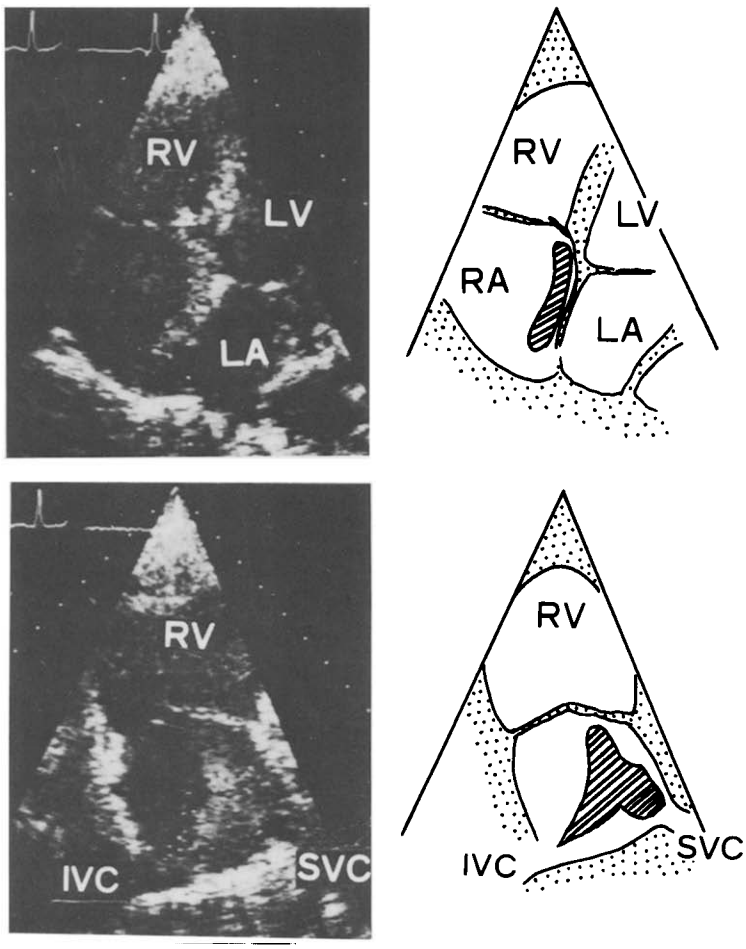

Figure 1. Right atrial blood flow recorded in the apical four chamber **(upper)** and sagittal **(lower)** views. **Upper panel**, In the apical four chamber view, red blood flow signals (shown as the **shaded portion** in the right schema) are recorded from the posterior wall to the tricuspid orifice along the atrial septum in late systole. **Lower panel,** In the parasternal right ventricular inflow tract view, red belt-like signals (shown as the **shaded portion** in the right schema) are recorded from the superior (SVC) and inferior (IVC) venae cavae and join together at the upper part of the right atrium (RA). They indicate the main pathway of right atrial inflow from the superior and inferior venae cavae. LA = left atrium; LV = left ventricle; RV = right ventricle.

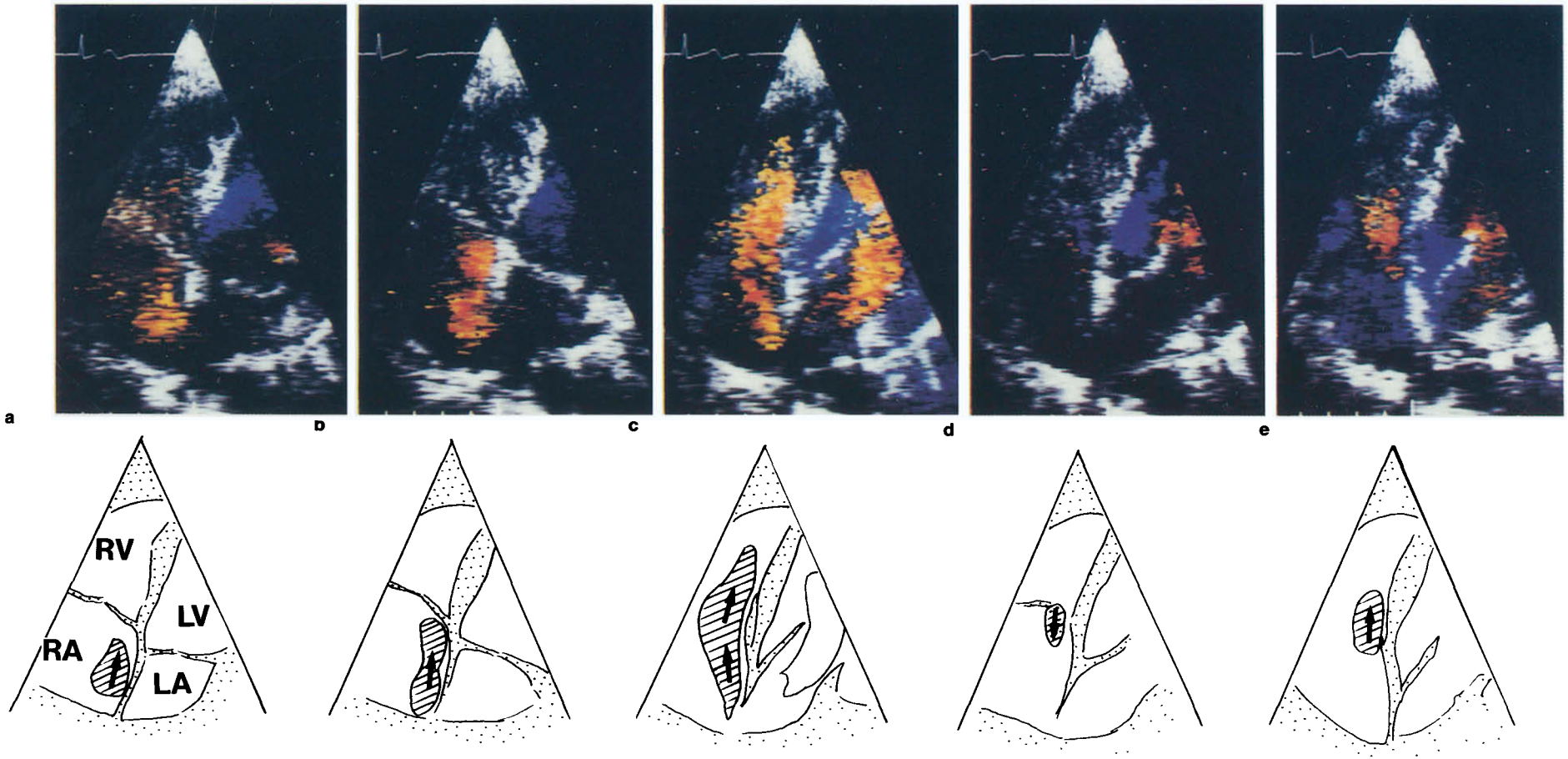

Figure 2. Phasic analysis of the right atrial (RA) flow pattern in the apical four chamber view. **a**, Mid-systole; a rapid flow (red signals) toward the tricuspid valve is recorded along the interatrial septum. **b**, Late systole; flow away from the tricuspid valve is recorded to the right side of the previous rapid flow. **c**, Early diastole; the red flow signal is recorded along the interatrial septum as a continuous belt-shaped area extending from the posterior part of the right atrium and entering the right ventricle (RV). **d**, Mid to late diastole; bluish signals are recorded from the right ventricle into the right atrium through the tricuspid orifice. **e**, Atrial contraction; reddish flow signals toward the right ventricle are recorded in a small range from the right atrium into the right ventricle through the tricuspid orifice. Abbreviations as in Figure 1.

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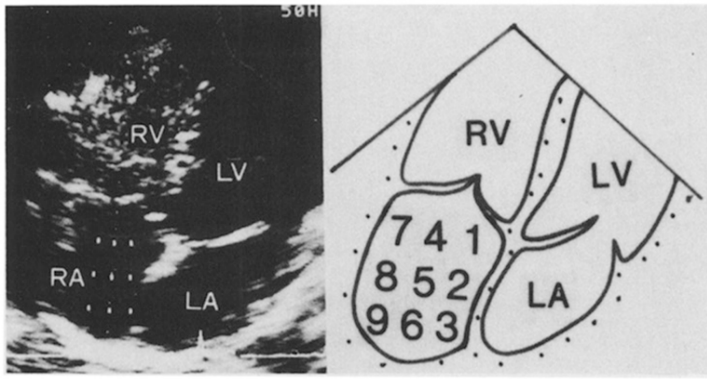
This reverse flow was recorded to the right of the previous rapid flow.

In early ventricular diastole, the reddish flow signals were recorded along the interatrial septum as a continuous belt-shaped area extending from the posterior part of the right atrium and entering the right ventricle through the tricuspid orifice. From mid-diastole to late-diastole, bluish slow flow signals were recorded from the tricuspid orifice to the medial part of the atrial cavity. In subjects with bradycardia, these bluish signals were recorded from the right ventricle into the right atrium through the tricuspid orifice during a prolonged mid-diastolic phase.

In the atrial contraction phase, reddish flow signals toward the right ventricle were recorded in a small range, moving from the right atrium into the right ventricle through the tricuspid orifice.

Flow in the right atrium was noted mainly along the interatrial septum and manifested a two-peaked pattern in mid to late systole and early diastole. In 19 subjects, the peak velocities of this flow measured by a velocity spectrogram averaged 35.2 cm/s in mid to late systole and 28.8 cm/s in early diastole (Fig. 3).

Right atrial flow pattern observed in the parasternal right ventricular inflow tract view. Reddish flow signals were usually noted as belt-like formations traveling from the inferior vena cava along the posterior wall, and then



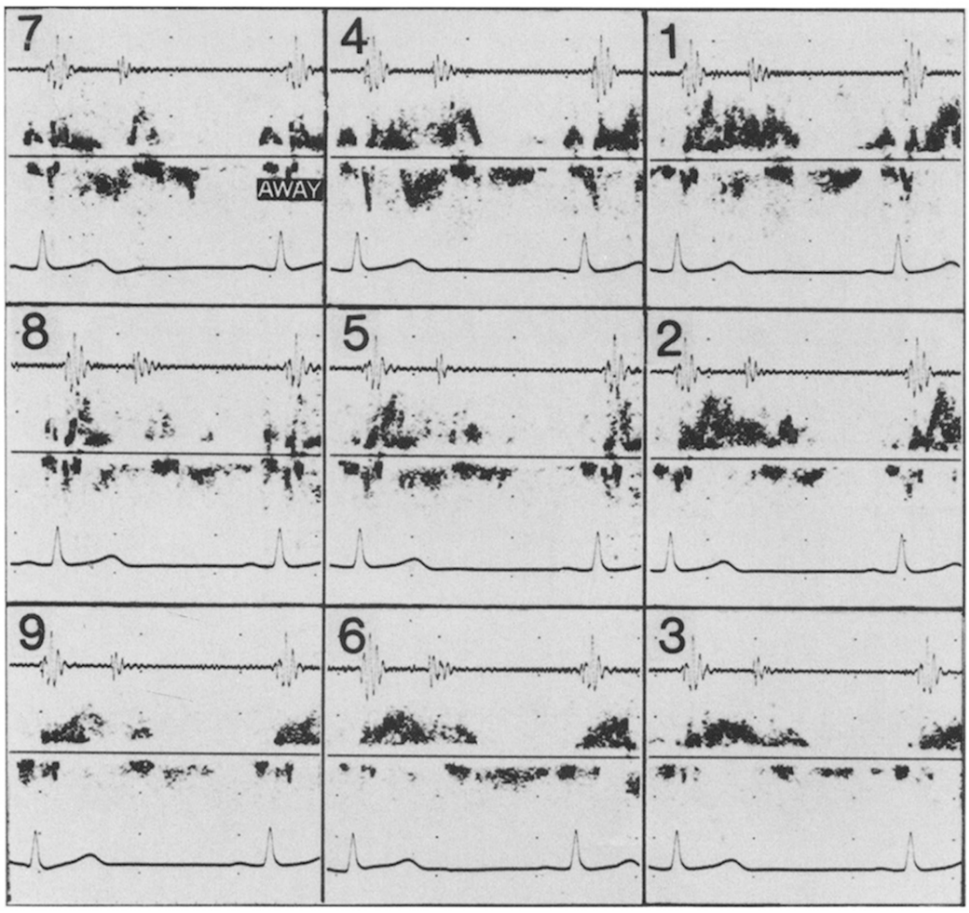


Figure 3. The velocity spectrogram of the right atrial flow in the apical four chamber view. **Upper panel:** The sample volume was set at the nine points in the right atrium as shown by the **dots** on the two-dimensional echocardiogram. **Lower panel:** The high velocity spectrograms recorded at the nine sites. The spectrograms at the sample volumes (1,2) near the interatrial septum show the two-peak pattern in late systole and early diastole. The phonocardiogram and electrocardiogram are also shown. Abbreviations as in Figure 1.

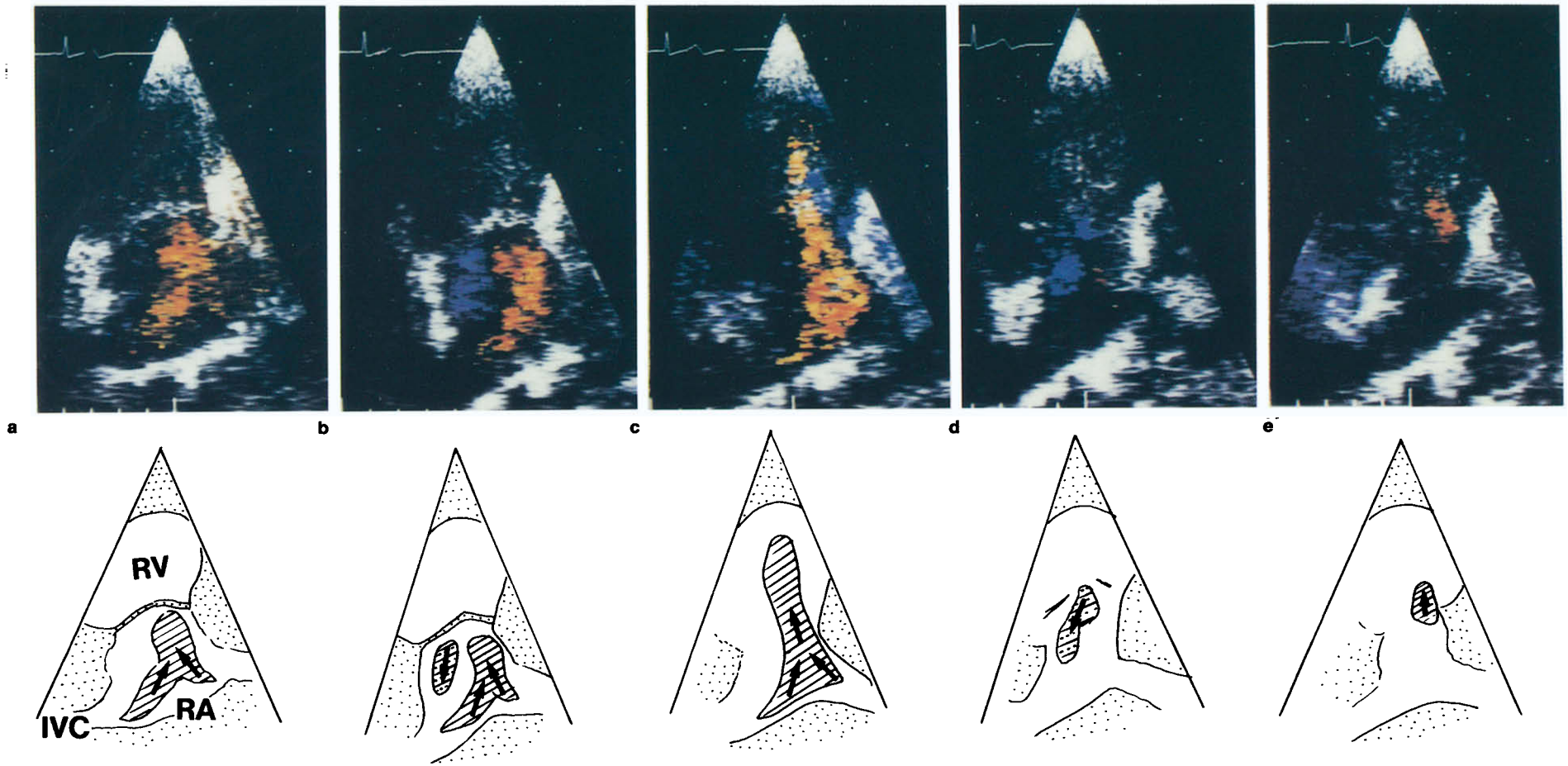


Figure 4. Phasic atrial flow pattern in the parasternal right ventricular inflow tract view. **a**, Mid-systole; red belt-like signals are recorded from the superior and inferior (IVC) venae cavae and join together at the upper part of the right atrium (RA). **b**, Late systole; bluish slow flow signals from the tricuspid valve are also recorded in the remaining area of the right atrial cavity. **c**, Early diastole; reddish signals spread over the right ventricular (RV) cavity through the tricuspid orifice. **d**, Mid to late diastole; bluish signals are noted over the central and anterior part of the right atrium. **e**, Atrial contraction; red signals are recorded near the tricuspid orifice in the right ventricle.

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from the roof of the right atrium toward the tricuspid orifice during mid to late systole. They appeared to indicate the main pathway of the atrial inflow from the inferior vena cava (Fig. 1,4).

In 9 of the 21 subjects, it was clearly demonstrated that flow from the superior vena cava joined with flow from the inferior vena cava at the upper posterior corner of the right atrial cavity. In late systole, slow flow from the tricuspid valve was recorded in the remaining area of the right atrial cavity. In early diastole, the area of the reddish signals spread over the right ventricular cavity through the tricuspid orifice, similar to findings in the apical four chamber view. During mid to late diastole, bluish signals were noted over the central and anterior areas of the cavity.

Observation in the parasternal three chamber view. The ostium of the coronary sinus was shown in the parasternal three chamber view. During mid and late systole reddish signals spread with a vaguely belt-like form from the ostium of the coronary sinus into the right atrial cavity in 3 of the 21 subjects. These signals had a narrow, belt-like configuration and their range was smaller compared with that of the flow from the venae cavae (Fig. 5). It is possible that signals indicate coronary sinus flow, but this hypothesis requires further study.

Respiratory changes. Right atrial inflow exhibited respiratory changes. The extent of the flow signal expanded and the flow velocity accelerated during inspiration and decreased during expiration.

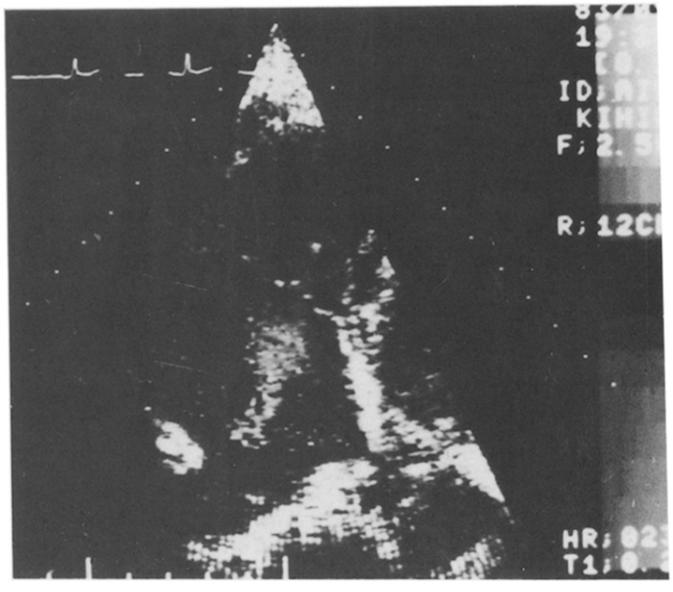
Figure 5. The right atrial flow in the parasternal three chamber view. Thin reddish belt-like signals (shown as the **dotted** portion in the **right schema**) are faintly recorded from the coronary sinus (**arrow**) into the right atrium which join the red flow signals from the venae cavae (**oblique-lined** portion in the right schema).

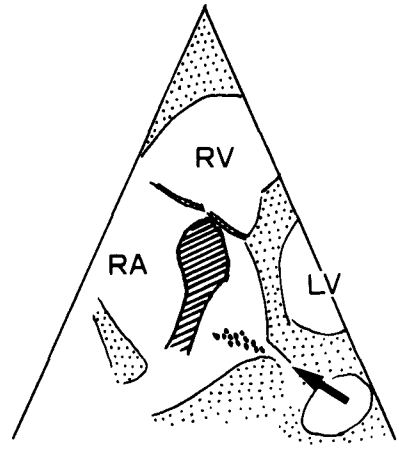
Discussion

The ultrasound pulsed Doppler technique is very sensitive in detecting intracardiac blood flow (6–9). However, the conventional pulsed Doppler echocardiogram provides only one spot signal information on the intracardiac blood flow. It is difficult to analyze the blood flow in the right atrial cavity by this method, because the flow enters the right atrial cavity from different sources. Using the real-time, two-dimensional Doppler imaging technique, however, spatially complex flow conditions can be observed.

The present study revealed that blood flowing from different venous sources does not mix immediately after entry into the right atrial cavity. Rather, flow from each source continues to move within certain belt-like pathways. Before the development of the two-dimensional flow imaging technique, conventional methods were unable to clearly detect this phenomenon.

Right atrial diastolic flow. The intraatrial flow pattern is determined by combining the results of the apical four chamber and parasternal right ventricular inflow tract views (Fig. 6). Atrial inflow from the inferior vena cava courses from the vein along the posterior wall of the right atrial cavity. It joins with the inflow from the superior vena cava at the posterocranial part of the right atrial cavity. Then, both flows move toward the tricuspid valve along the interatrial septum and the roof of the right atrial cavity; all flows from the venae cavae moving toward the right ventricle through the right atrium travel along the same pathway in early diastole. During ventricular late systole and ventricular mid to late diastole, another flow moving away from the tricuspid valve is noted over the central and lower right portion of the right atrial cavity, that is, to the lower right of the caval inflow. The flow along the interatrial septum was imaged with the greatest ease in mid-systole, with the





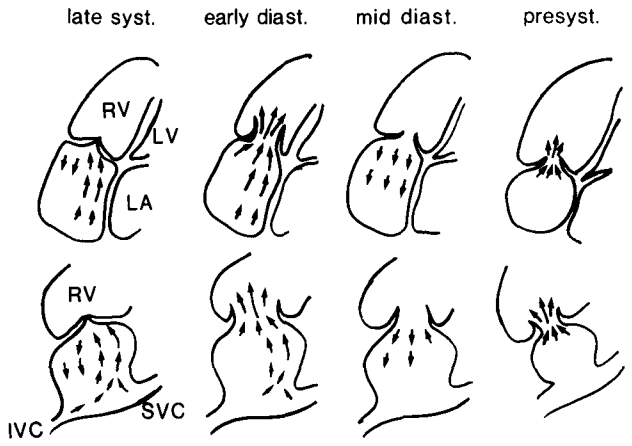


Figure 6. Diagrams presenting right atrial flow recorded in apical four chamber (**top**) and parasternal right ventricular inflow tract (**bottom**) views. The **upper diagrams** show the four chamber view, the **lower diagrams** the parasternal right ventricular inflow tract view. The corresponding **vertical pairs** show the flow patterns recorded at simultaneous phases. Late systole (syst.): Blood flow from the inferior and superior venae cavae moves along the interatrial septum toward the tricuspid valve. Blood flow turning away from the valve is shown at the right caudal part of the right atrium. Early diastole (diast.): Blood flow along the interatrial septum through the tricuspid orifice into the right ventricle (RV). Mid to late diastole: Blood flow away from the tricuspid orifice into the right atrium. Presystole (presyst.) and atrial contraction of the right atrium: Flow within a small range through the tricuspid orifice into the right ventricle.

peak velocity in the right atrial cavity over one cardiac cycle. Therefore, atrial relaxation is considered to be the most powerful factor promoting intraatrial blood flow.

The right atrium has been considered the chamber through which flow passes from the caval vein to the right ventricle. This view appears to be supported by our results in the present study, in which flow was depicted coursing along the interatrial septum. Flow away from the tricuspid valve, noted in the central part of the right atrial cavity, is assumed to be an eddy current resulting from the former flow toward the tricuspid valve. The major route for right atrial flow must by the upper part along the interatrial septum; the lower right half of the right atrial cavity is assumed to contain pooled blood flow.

Right atrial systolic flow. Flow during atrial systole is recorded only around the tricuspid valve orifice and not in the remaining portion of the right atrial cavity; therefore, the flow that is ejected into the right ventricular cavity during atrial contraction is assumed to contain mainly pooled blood from the right atrial cavity. Slow flow from the right ventricle toward the right atrium must reflect the semiclosure of the tricuspid valve in this phase.

Coronary sinus inflow. In the present study, inflow from the coronary sinus was virtually undetectable. We suggest two possible reasons for this difficulty in detecting the inflow from the coronary sinus: 1) The blood volume of the coronary flow may have been small in comparison with blood volume from the superior and inferior venae cavae; and 2) because the angle between the ultrasound beam and the flow direction appeared to be nearly perpendicular, the velocity in the direction of the ultrasound beam may have been slower than 7.5 cm/s, which is the lower limit of display.

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